

DETAILED DESCRIPTION OF THE INVENTION

(Field of Industrial Application)

The present invention pertains to a non-linear compensation system in a signal amplifying device, particularly to the non-linear compensation system for an amplifier effectively applicable to a transmitter installed in the earth station for satellite communication systems.

(Problems of the Prior Art to Be Addressed)

A transmitter installed in the earth station for satellite communications is required to have a structure to produce a high transmission output. The reasons for it are: Its relaying distance is very long; One same transmitter is used in common to amplify multiple signals. If the transmitter is operated near a saturation point, interference is generated between the signals due to non-linear characteristics of the input and output of the transmitter, generating harmful, unnecessary signals. Therefore, not only the requirement stipulated by the radio wave law for an unnecessary wave level cannot be met but also the harmful interference occurs to the other signals. Therefore, the transmitter is generally operated at the output several times lower than the maximum output, to prevent the generation of the unnecessary waves.

Various methods were proposed in order to improve the non-linear characteristic of the transmitter, and they can be basically categorized into a predistortion method and a feed-forward method. In the former method, a distortion-generation circuit having the reverse input/output characteristics to those of the electric amplifier is installed on the side of input terminal, to improve the total input/output characteristics. In the latter method, the output/ input of the amplifier are compared to detect the distortion component from the difference between them, and this difference is amplified by a second amplifier and added in reverse phase at the output terminal side of the amplifier, to offset the distortion component.

Fig. 2 shows a schematic diagram of the prior art predistortion method. In the figure, B indicates the amplifier having the non-linear input/output characteristic, and A the distortion generator having the input/output characteristics reverse to the amplified input/output characteristics. The non-linear characteristic of the amplifier B is offset by the distortion generator A.

Fig. 3 shows one example of the structure of said distortion generator A. In the figure, 1 indicates the input signal, 2 and 3 the branch circuits, 6 and 7 the delay line, 31 the non-linear elements made of amplifier or diode, 32 the variable attenuator, 9 the subtracting circuit, 18 the adding circuit,

and 19 the output signal. Of them, the branching circuit 3, the delay line 7, the non-linear element 31, the variable attenuator 32, and the subtracting circuit 9 constitute the reverse distortion generation circuit 30.

The distortion generator operates as follows. The input signal 1 is split at branch circuit 2, and one of them is input into the reverse distortion generation circuit 30 surrounded by the dotted line shown in the figure. The signal is again split in the circuit 30, and one of them is input into a non-linear element 31 for indicating the non-linear characteristic. In this example, an amplifier is used, but it can be substituted by the non-linear element such as a diode. On the input side of the non-linear element 31, the distortion is amplified by the amplification of the input signal, but it is reduced by the non-distortion signal that passed through the other delay element 7, so the distortion component alone is output to the output terminal of the subtraction circuit 9. To satisfy these conditions, the signal levels at the time of small signal operations from both routes have to be equal and their phases have to be set in a reverse phase. In this example, the phase is adjusted by the delay line 7. The variable attenuator 32 is used to adjust the signal levels. After the adjustment, the distortion output alone is output to the output terminal of the subtraction circuit 9, and in the adding circuit 18, the distortion is added to the signal that passed through the delay line 6. As

a result, the output 12 from the adding circuit 18 becomes a composite of the signal component and of reverse distortion component, so the overall characteristics of the branch circuit 2 through the adding circuit 18 demonstrate the input/output characteristics reverse to those of the main amplifier B to be connected to this distortion generator A.

In the aforementioned prior art, the manufacture of the distortion generator A having the distortion characteristic reverse to that of the main amplifier B is focused. In general, however, it is difficult to make the reverse component that can simultaneously offset in a broad operation range the amplitude distortion and the phase distortion that constitute the distortion of the amplifier. The reason for it is that the distortion characteristic of the non-linear element 31 of Fig. 3 is fixed as the characteristic unique with the element.

(Objective)

The present invention, to solve the aforementioned problems, attempts to present a non-linear compensation system using the predistortion method, whereby the non-linear characteristic of the main amplifier can be compensated in a broad range. Said system is characterized in that another distortion generator having a different operation point is

added to the reverse distortion generation circuit, to generate the reverse distortion extremely similar to the prescribed distortion characteristic.

(Structure and Operation of the Invention)

The present invention is explained below in detail.

Fig. 1 shows one embodiment example of the present invention. In the figure, 1 indicates the input signal, 2 – 5 the branch circuits, and 7 and 8 the delay lines, which actually have the phase adjusting function. In the same figure, 9 and 9a indicate the subtraction circuits, 10 – 14 and 14a the variable attenuators, 15 and 15a the non-linear elements, for which the amplifier is used in this example, 16 the phase shifter, and 17 and 18 the adding circuits.

The operation of this embodiment example is explained below. The input signal 1 is split by the branch circuit (D_1) 2, and one of the signals is input into the adding circuit 18 via the delay line 6. The other signal from the branch circuit 2 is input into the branch circuit 3, and one of them is input into the branch circuit (D_3) 4 [sic]. One of the outputs from this branch circuit 4 is input into the subtraction circuit 9 via the delay line (II) 7. Other output from this circuit is input into the non-linear element (amplifier) 15

via the variable attenuator (att_1) 10, and the output from the non-linear element 15 is input into the subtraction circuit 9 via the variable attenuator (att_2) 11. By these two routes between the branch circuit (D_3) 4 and the subtraction circuit 9, one distortion component can be produced. In this example, the variable attenuator (att_1) 10 is inserted to determine the operation point of the amplifier 15. More specifically, by increasing this attenuation amount, the input level is reduced, and the saturation point of the amplifier 15 is changed relative to the level of the input signal 1. On the other hand, the variable attenuator (att_2) adjusts the output of the subtraction circuit 9 that has passed the delay line (II) 7 to be zero at the time of small signal operation. By this series of adjustments, the output from the subtraction circuit 9 becomes zero at the time of small signal operation, so when the amplifier 15 generates the distortion by the increase in input signal 1, only the distortion output alone is output from the output terminal of the subtraction circuit 9.

Fig. 4 shows this condition. The horizontal axis indicates the input signal level. The upper section of the vertical axis indicates the distortion output that was changed by adjusting the operation point of the non-linear element 15 by the variable attenuator (att_1) 10; the lower section indicates

the output level of the variable attenuator (att₂) 11 in which the phase is inverted.

In this case, since an amplifier is used for the non-linear element 15, by changing the operation voltage of the amplifier, e.g., the collector voltage of the transistor amplifier, the same effect as that produced from changing the attenuation amount of the variable attenuation (att₁) 10 can be produced in a relatively narrow change. The output from this subtract circuit 9 is input into the adding circuit 18 via the variable attenuator (att₆) 14 and adding circuit 17. And, in this adding circuit 18, this output is added to the signal that passed through the branching circuit (D₁) 2 and delay line (I) 6. At this time, the delay line (I) 6 is so set that the electrical delay amount will be equal in the two routes from the branching circuit (D₁) 2 to the adding circuit 18. More specifically, in this adding circuit 18, the composite phase is set by the delay line (I) 6 so that the vector sum of the signal from the delay line (I) 6 and of signal output from the adding circuit 17 will have the reverse characteristic to the characteristic of the input/output of the amplifier. Fig. 5 shows the condition of this composite vector. Here, $\overline{OP_0}$ indicates the output from the delay line (I) 6, and $\overline{OP_1}$ indicates the composite vector of this output and of distortion component output. Both signals use the value more normalized than the input signal level 12. By

changing the input signal level here, the size of the composite vector is changed along the curved line of $P_0 - P_1$. When the composite phase θ is changed at the time of synthesizing, the track of P_1 point becomes circular. The distortion is composed of amplitude and phase components, and the phase distortion is mostly generated by output signal phase delay caused by the increase in the input signal. Accordingly, the phase of reverse distortion output from the subtraction circuit 9 is increased as the distortion is increased.

As explained above, to offset the distortion in a broad range, it is necessary to select the non-linear element generating the reverse non-linear characteristic including the phase characteristic. At present, however, it is difficult to implement this idea. Therefore, in the present invention, a second distortion output circuit 20 is newly added to produce a nearly ideal reverse distortion characteristic. The operation characteristic of this added circuit is basically the same as that of reverse distortion circuit mentioned earlier, and only the distortion output of the amplifier 15a alone is output to the output terminal of the subtraction circuit 9a. This output passes through the variable amplifier (att5) 14a and the phase shifter 16 to be input into the adding circuit 17.

The operation of this circuit is explained below. Suppose, here is an instance wherein the first distortion output circuit 20 is applied to a general predistortion circuit and the amplitude distortion in the input/output of the traveling-wave tube amplifier is compensated, the phase distortion cannot be sufficiently compensated. This instance is shown in Fig. 6 (a).

At this time, the reverse distortion of the first distortion output circuit 20 has the relation to the input signal level like that shown in Fig. 6 (b). Therefore, the second distortion output circuit 21 is set, as shown in Fig. 6 (c). As mentioned earlier, this can be set easily by adjusting the variable attenuator (att_3) 12. In other words, in the second output circuit 21, the operation point of the distortion generation is generated with some delay relative to that of the distortion output circuit 20. The distortion output of the second distortion output circuit 21 is input into the adding circuit 17 via the variable phase shifter 16. In this adding circuit 17, the vector sum of the distortion components of the first distortion output circuit 20 and of second distortion output circuit 21 is output and synthesized with the input signal from the branch circuit 2, which is the output from the delay line (I) 6, in the adding circuit 18.

Fig. 7 shows an instance wherein the phase of the output signal 19 is controlled by the output signal from the second distortion output circuit 21.

As the input signal level is increased, the distortion is generated in the first distortion output circuit 20. As a result, the input/output characteristics are transformed from $\overline{OP_1}$ to $\overline{OP_1'}$, as shown in Fig.7. For the sake of convenience, this example assumes that in the first distortion output circuit, the phase distortion is not generated as the input level is increased.

In the case of setting, in the variable attenuator (att₃) 12, the output level relative to the input signal level is a projection to the vertical axis of $\overline{OP_1'}$, and as the input level is increased, the output level is increased fast. So, the input/output characteristics having the reverse input/output characteristics of the compensating amplifier can be implemented. Then, suppose, the second distortion output is added to this. For the same of convenience, the operation point of P_1' is used for explanation. Here, $\overline{P_0P_1''}$ indicates that the second distortion output signal is orthogonally synthesized to $\overline{OP_1}$. At this time, the size of composite signal level is changed from $\overline{OP_1}$ to $\overline{OP_0}$, and the phase is shifted by θ_1 . The phase difference between both at the time of synthesis can be properly set by adjusting the phase shifter 16, and it is evident that the track of P_0 at the time of changing the phase difference by 0 - 360° becomes circular, as shown in Fig. 7. The maximum phase deviation is generated when $\overline{OP_1''}$ and $\overline{OP_0}$ are orthogonal to each other. In this case, the input/output amplitude characteristics of $\overline{OP_1'}$ are

hardly changed. The level and phase of the composite signal is changed by the phase difference at the time of synthesis, so it is possible to change the amplitude alone without changing the phase characteristic.

In the above explanation, the phase of the first reverse distortion output of the first distortion output circuit 20 was zero. But, in reality, the reverse phase distortion is present, so the reverse phase distortion is total sum of the reverse phase distortion produced from the second reverse distortion circuit 21 and of the first reverse phase distortion.

In the example explained above, the output from the second distortion generation circuit was added to the output from the first distortion generation circuit, and subsequently, the sum of them was added to the input signal, but the same effect will be produced if the output from the first distortion generation circuit is added to the input signal and the output from the second distortion circuit is added to this sum.

(Advantage)

As explained above, by adjusting the operation point of the second distortion output (the output level of the variable attenuator att₃ 12), the input/output characteristics and the input/output phase characteristics can be made similar to the desired characteristics, so the reverse distortion generation circuit is extremely effective.